AN OFF-AIR 198kHz FREQUEN

Need a
frequency
calibration aid?
Dave Allen
G8XRS shows
you how to lock
onto the
Droitwich
transmissions
to create a
very stable
frequency
source.

his design for a frequency reference source was inspired after driving past the legendary and tall, 198kHz transmitting masts located alongside the M5 motorway at Droitwich in Worcestershire. The signal sender at this site is said to be remarkably accurate and stable so, I thought that by using the carrier of this transmitter a suitable signal could be derived to check the accuracy of my selection of frequency counters - all two of them.

My proposed frequency source has been used with a popular hand-held counter in the £100, range made by Thurlby Thandar Instruments. The circuit has also been used successfully with an ancient Farnell counter which uses 'nixie' tubes for the display.

The Circuit

The circuit of the unit shown in **Fig. 1**, comprises four distinct sections. The antenna input tuned circuit L1 and C1, C3 and C4, the r.f. gain stage, Tr1, which consists of a 3N201 dual-gate f.e.t. and its surrounding components, the phase locked loop/in-lock indicator, IC2, and of course a source of regulated power, IC1.

The long wave antenna consists of a home-wound coil L1 and L2, made up of 200+20 turns (give or take a few) of fine (0.305mm or 30s.w.g) enamelled copper wire close-wound at the centre of a 180mm long x 10mm (7 \times 3/8 inch) diameter ferrite rod. The rod is first covered in a length of heat-shrink sleeving which acts as the coil former.

Accuracy

For the average radio enthusiast, the Droitwich signal is incredibly accurate. According to the BBC, the frequency of the 198kHz carrier is held at 2 parts in 10¹¹. For those who are fond of lots of zeros that is 2 parts in

100,000,000,000 or two parts in one hundred thousand million.

Droitwich.

The Droitwich day-to-day stability is also quite good at 1 part in 10^{11} . This level of accuracy and stability is achieved by controlling the carrier frequency with a Rubidium gas cell standard whose performance is checked against the Caesium Standard at the National Physical Laboratory, which in turn, closely monitors the carrier emanating from

There are, however, two lesser known Radio Four 198kHz transmitters in the UK, one of which is located at Burghead (east of Inverness) and radiates 50kW. The other is at Westerglen (between Glasgow and Stirling) and is also 50kW. Both are synchronised to the Droitwich transmitter and could be used to good effect. My home town is Cheltenham in the Cotswolds and lies about 40 miles south of Droitwich.



Winding The Coil

Let's start with winding the coil antenna. Firstly make a mark 65mm in from one end of the sleeved ferrite rod; this will be the start point. A strip of thin double-sided adhesive tape, placed at the centre of the rod. This will hold the turns in place.

Have a look at the illustration of **Fig. 2**, then **carefully** close-wind on the 20 turns of the wire for L2 onto the rod. Bring a loop of wire out and twist it together. This forms the earthy connection of L1/L2 leaving a little spare at either end for termination. Then, again carefully, wind on a further 200 turns for L1.

As the wire used for the coil is rather delicate it's a good idea to terminate the ends with a short length of 7/0.2 mm

stranded hook-up wire, soldered to ends of the coil. The flying leads can then be anchored to the rod with a piece of insulating tape or a smear of suitable adhesive thus making the antenna more manageable when connecting the assembly to the rest of the circuit.

Tuning Capacitors

The tuning capacitors are mounted on the circuit board and, with L1 forms the input tuned circuit. Resistor R2 in parallel dampens the tuning slightly. As with any r.f. tuned circuit there is inevitably a certain amount of stray capacitance but this appears to make little difference in the present application.

• Fig. 1: The circuit of a



ICY SOURCE

A small positive bias is required on g2 of Tr1 to ensure correct quiescent operation of the stage, and the method used appears to be a good choice. This first stage, wired as a common source amplifier is coupled to the input (pin 3) of the phase locked loop (p.l.l.) (IC1) and to Sk1.

The phase locked loop used in my design, is an LM567 i.c. which takes the signal as a whole from the output of the r.f. gain stage. It then removes the modulation from this signal and produces a square wave signal at the 198kHz carrier frequency.

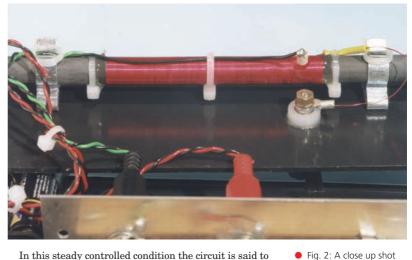
Tone Detector

The LM567 i.c. is primarily intended for use as a tone detector, in this case the tone is the 198kHz carrier. This device was chosen because, as it's an easy-to-use p.l.l., but it also contains a useful tone detected signal. The LM567 p.l.l. comprises a voltage controlled oscillator (v.c.o.), phase comparator and a circuit that indicates when the frequency of the v.c.o. is locked to the input signal at pin 3.

The free-running frequency of the v.c.o. is defined by C13, R7 and R8 and it.'s output is compared, in the phase comparator, with the signal from the r.f. stage. Should the two signals fall out of step, a series of error voltage pulses are produced representing the direction of the error.

The error pulses, when filtered and smoothed by the loop filter (C12), give a d.c. voltage that's internally connected to the control input of the v.c.o. that, automatically, adjusts the v.c.o.'s frequency until it again matches the average frequency of the 198kHz r.f. input. Eventually the loop reaches a steady state when the two signals are of the same frequency.





In this steady controlled condition the circuit is said to be locked, the modulation is effectively removed from the radio signal and the v.c.o. output then becomes a squarewave at the carrier frequency. The v.c.o. output from pin 5 of the LM567 is a.c. coupled to the output socket which in turn goes to your counter.

In essence, the tone detector output is an an open collector npn transistor that is switched on when the frequency of the v.c.o. is equal in frequency to the input signal. This drives a low current l.e.d. (D2) which forms the 'in-lock' indicator. You'll find this l.e.d. a great aid to setting-up, as when D2 is lit, the circuit should be in lock.

of the ferrite rod.
Winding the coil can be
a rather difficult task
with thin enamelled
copper wire.

Mechanical Consideration

There are some mechanical considerations to bear in mind in order for the frequency reference to function correctly. My prototype unit is shown in the photograph of Fig. 3 and this general layout should be followed. The ferrite rod antenna should be kept away from the output of the instrument to prevent unwanted coupling, thus causing false readings.

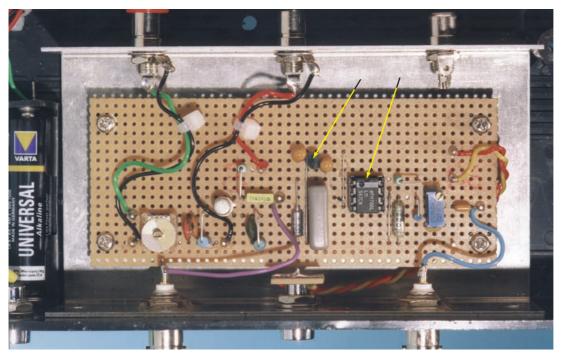
Isolation of the antenna and output is achieved by placing the circuit board containing the active components, sockets and the in-lock indicator inside an

aluminium box, which is then fixed inside a plastic enclosure housing the rest of the components.

Before commencing any soldering or wiring it is good idea to prepare the enclosures and circuit board for subsequent mounting. After unwrapping the plastic box, remove the bolts holding the two sections of the enclosure together you will notice two plastic lugs on each half of the box. Chop 'em off!

After unwrapping the aluminium box retain the simple 'U' shaped section and put the other, more complex, half of the enclosure to one side for the time being. The next stage of construction may seem a little complicated but I am sure that with the aid of the photographs things will go smoothly.

 Fig. 3: It's a good idea to follow this general layout when you come to making your own unit. The blue terminal post is for attaching an external long wire antenna.



• Fig. 4: A prototype unit, is shown here to give an idea of how easy it is to build. This general layout should be followed to keep the input and output as far apart as possible. Please note R4 is fitted under the board, and there are differences around the C7/8 area.

- Take the bottom half of the plastic box and insert one of the panels supplied with the box into the moulded slot. This is the 'front' panel.
- 2: Take the simpler 'U' shaped section of the aluminium box and place one of the long sides up against the rear of the front panel, ensuring it is placed up in the 'top left' corner of the plastic box.
- 3: You will see two pre-drilled holes in this 'U' shaped aluminium section. Using these holes as a template make two pencil marks on the the rear of front panel then drill two 6BA clearance holes on these marks.
- 4: Bolt the aluminium 'U' section and the front panel together; these nuts and bolts will be removed after drilling the holes for Sk1, Sk2 and the bezel fixing for D2.
- 5: Now draw a line on the front panel between the two bolt heads centres mentioned in para 4 above.
- 6: Make a pencil mark (for the l.e.d.) in the centre of the line and a pencil mark about 35mm either side (for the sockets) and drill suitable holes through the front panel and aluminium 'U' section.
- Mount the l.e.d. bezel in the central hole with Sk1 and Sk2 either side. The nuts and bolts holding the 'U' in place can now be removed.

The Circuit Board

Now for the circuit board and one of my prototypes is shown in the photograph of **Fig. 4**. Prepare a piece of strip-board 17 strips x 44 holes long by drilling 4 x 6BA clearance holes, one in each corner, three holes 'in' and 'down' from each corner. Using holes in the circuit board as a template mark out four holes in the middle of the base of the 'U' shaped aluminium section and drill four holes and mount four 10-15mm long metal board spacers using suitable short bolts.

The small number of components can be mounted on the board and termination pins inserted for off-board connections. The flying leads from L1 and the leads for power were taken into the box via 'phono' sockets on the rear wall of the 'U' channel.

The completed circuit board can be mounted on the four metal spacers fitted previously on the 'U' shaped aluminium section; note that two of the spacers provide the earthing for the board.

The ferrite rod assembly is attached to the rear panel of the plastic enclosure with Terry tool clips which are held in place by short bolts and nuts. A screw terminal is mounted on the rear of the plastic box for the external antenna connection (see photographs).

The setting up procedure is best done with the aluminium box completing the screened enclosure. Two holes need to be drilled in the lid of the screened box, depending on the position of C1 and the oscillator tuning preset potentiometer (R7). So, a little care in measuring out is called for here.

After drilling the two adjustment holes the two halves of the metal case can be assembled. Two of the four self-tapping screws supplied with the aluminium box can be now inserted through the back of the metal box. Now two longer self-tapping screws

will be required to attach the previously drilled holes in the front panel to the aluminium box within the main plastic enclosure.

System Setting Up

There are two methods to setting up the system. The first method uses an oscilloscope and frequency counter. With your unit completed, connect your oscilloscope, via a short low capacitance screened lead to Sk1 - r.f. monitor output. Then adjust C1 for maximum amplitude, including the modulation, as viewed on the oscilloscope screen.

When this operation is complete you need to disable the r.f. input stage by placing a short circuit across L1 (or disconnecting the plug if this is what you have done) . Now connect the output proper (Sk2) to your frequency counter and adjust R7 until a reading of 198kHz is noted. A couple of kHz in either direction will make little difference.

Reconnect L1 or remove the short circuit from the tuned circuit and the in-lock indicator (D2) should light up, showing that the phase-locked loop is in fact locked to 198kHz. A reliable reading should now be shown on your frequency counter.

Alternative Method

The alternative method of setting up is similar to the one described above, except that instead of using an oscilloscope a high impedance voltmeter and an r.f. probe are used to measure the r.f. output at Sk1. As before adjust C1 for maximum reading on your meter.

If you don't have an r.f. probe now could be the time you constructed one of these useful devices, the very simple circuit is shown in **Fig. 5**. In essence the probe takes an r.f. signal and detects this signal by rectification using a germanium diode. The resultant detected voltage is smoothed to provide a steady d.c. voltage suitable for the input of a high impedance voltmeter (e.g. a digital type).

I managed to squeeze the r.f. probe into an empty Tippex pen barrel. A better choice could be a jumbo size magic marker barrel as there is plenty of space to mount the components. The probe tip was scavenged from an old test probe and attached to the plastic barrel using a blob of epoxy resin after soldering one end of the capacitor.

Power Supply

I've designed the system to run from an internal a 9V battery power supply that consists of six 1.5V cells mounted in two three-bay holders. These holders are mounted to the base of the main enclosure using 6BA nuts and bolts (see photographs).

Power from the battery is taken, via S1, to the circuit board with two lengths of hook-up wire. These leads are dealt with similarly to the antenna winding flying leads, in that I've used a phone plug/socket arrangement. A power on indicator has been incorporated and consists of an l.e.d. and resistor (D1/R1) which are mounted on the front plastic panel.

In order to stabilise the frequency of the voltage controlled oscillator within the LM567, a small regulator (IC1) has been included. It would be perfectly feasible to use a 78L05 type instead, if one is available. This i.c. regulates the main 9V supply rail down to a stable 5V which according to the application notes is a typical operating value for the LM567.

Excellent power supply decoupling for the circuit is provided by C2, C5, C9 and C10. Note C2 is wired directly across the i.c. socket pins on the track side of the circuit board for maximum effect so, ensure a physically small component is used in this position.

Current consumption of the finished frequency reference source is in the region of 20mA and for those who think this is too much of a drain on the battery there is no reason why an outboard 9-12V power should not be used.

The type of coaxial power socket fitted to the plastic box is up to the individual but it will probably be of the standard coaxial variety which will suit most plug-top '9V' adaptors likely to be encountered. An alternative is to feed the unit from the station 12V supply, which will work just as well.

How To Use It?

If you're wondering how you would use the unit, it couldn't be simpler! The Unit is coupled to your digital counter and the reading noted. If you have access to the innards of your counter, then you can adjust the counter's timing crystal trimmer capacitor to give a reading of 198 000Hz.

(The counter should present a very light loading on the output of the unit, or a simple c.m.o.s. buffer stage may be added to isolate pin 5 of IC2 from the counter. **Editor**.)

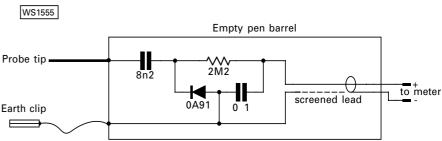
If your counter does not have a calibration capacitor, or if you cannot gain access to the insides then you just have to apply the little calculation, shown below, to every reading that you take with the counter.

F eal = F_{count} * factor

Where
F_{real} = Real frequency
F_{count} = Displayed frequency
factor = count displayed
198 000

The 'factor' term used above is derived from the actual reading the counter shows when reading the 198kHz reference signal divided by 198 000. (Its value is likely to drift more with temperature, than with time on most of the cheaper digital counters. So, a temperature variation chart could be plotted if you know what the temperature is each time you measure and calculate the 'factor' value! Ed.)

To really put the frequency reference source through its paces it was taken for a holiday to Lizard Point at the far end of Cornwall and reliable results were obtained. So, this would indicate the possible range attainable with the finished instrument.



External Antenna

An input for an long/random wire antenna has been catered for. This is for those who live in a less favourable location with regards to signal strength on 198kHz. The circuit simply consists of a long wire attached to the screw terminal on the back panel. Please note, C1 may possibly need a very slight adjustment to restore maximum output from the r.f. gain stage.

 Fig. 5: A simple diode r.f. voltmeter may be used to set up this unit or other simple r.f. tuned circuits.

Other Stations

As a bonus, the tuning range of the v.c.o. section of the LM567 covers all of the long wave band so, it's possible to tune to other stations, that are sufficiently accurate, and have a reasonable signal strength. A certain amount of experimentation may be

required with regards to the value of the components in the input tuned circuit.

Some long wave transmitters worth trying are:

Atlantic 252 (252kHz - 500/100kW) if you happen to live in the wilds of west Wales or in Ireland.

Luxembourg (234kHz - 2MW),

Radio Monte Carlo (216kHz - 1.4MW)

Saarlouis

(183kHz - 2MW)

The above continental transmitters might be worth a try if you are based on the east coast of England or in western or central Europe.

BBC Engineering

May I say a big thank you to the BBC engineering department, where a very helpful lady, whose name I am unsure of, provided me with the information sheet regarding the 198kHz transmitter at Droitwich, to **David Evans** who took some original photographs and who penned the section on the phase-locked loop and to **Rosemary** who turned the selection of words into English.

PW

Shopping List

Resistors 560Ω R5 680Ω R₆ R1 1kΩ R3 $1.5k\Omega$ 2.7kO R8 $100k\Omega$ 2 R2, R4 Variable (20t Cermet type) $5k\Omega$ R7

Capacitors

Miniature disc Ceramic 82pF C4 100pF C3 1 820pF 1 C13 100nF 5 C2, C6, C7, C10, C14 Miniature Polyester 2.2nF **C8** 680nF C12 1 Electrolytic (tantalum) C11 $2.2 \mu F$ 1 C5, C9 10µF 2 Variable (foil trimmer)

Semiconductors

65pF

3N201	1	Tr1 (or similar m.o.s.f.e.t.)
HT7250	1	IC1 (or 78L05 type)
LM567	1	IC2
lade	2	type and colour to suit

C1

Miscellaneous

A ferrite rod (180×10mm), a length of heatshrink sleeving (see text), enamelled copper wire (see text), an ABS plastic box (Maplin BZ76), an aluminium box (Maplin LF08), stripboard, connecting wire, battery holder, plugs and sockets, switches and other small items to suit.